

EEVC RESEARCH IN THE FIELD OF IMPROVEMENT OF CRASH COMPATIBILITY BETWEEN PASSENGER CARS

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Paper number 444

ABSTRACT

EEVC Working Group 15 (Compatibility Between Passenger Cars) has carried out research for several years thanks to collaborative project funded by the E.C. and also by exchanging results of projects funded by national programmes. The main collaborative activity of the EEVC WG15 for the last four years was a research project partly funded by the European Commission, where the group made the first attempt to investigate compatibility between passenger cars in a comprehensive research program. Accident, crash test, and mathematical modelling data were analysed. The main result was that structural incompatibilities were frequently found and identified as the main source of incompatibility problems but were not easy to quantify. Unfortunately as little vehicle information other than mass is recorded in most accident databases, most analyses have only been able to show the effect of mass or mass ratio.

Common ideas to improve compatibility have been reached by this group and from discussion with other research groups. They will be investigated in the next phase, where research work will concentrate on the development of methods to assess compatibility of passenger cars. The main idea is that the prerequisite to improve crash compatibility between cars is to improve structural interaction.

The most important issue is that improved compatibility must not compromise a vehicle's self protection. Test methods should lead to vehicles which show good structural interaction in car to car accidents. Test methods to prove good compatibility may be an adaptation of existing regulatory test procedures (offset deformable barrier test or full width test like in the USA) for frontal impact or may be new compatibility tests. Additional criteria, e.g. impact force distribution, and maximum vehicle

deceleration or maximum vehicle impact force should result in compatible cars.

Attempts will be made to estimate the benefit of a more compatible car fleet for the European Community.

INTRODUCTION

In a research project partly funded by the European Commission (EC), EEVC Working Group 15 (Compatibility) made a first attempt to investigate compatibility between passenger cars. Accident, crash test, and mathematical modelling data were analysed. Partial funding came from the 4th EC Framework Program and lasted from July 1997 to December 1999.

The full report [1] is available from the EEVC. The research approach and first results were reported at the 16th ESV-Conference, Windsor-Canada 1998 [2].

This paper presents the outcome and conclusions of this research project in combination with the results of discussions within the group since the end of the project, where activities have been sponsored by national research programmes.

OBJECTIVES OF THE RESEARCH PROJECT

Road accidents are the greatest source of accidental death throughout the European Union. In 1997 within the European Community, about forty-five thousand people were fatally injured in traffic accidents. More than twenty three thousand of these casualties were car occupants.

Road accident configurations are extremely varied. Impact angle, overlap, impact point and speed are just a few of the parameters describing an accident. In a car to car accident, isolated stiff elements such as the longitudinals in the frontal car structure may be aggressive to other cars. The poor way in which they interact with the structures of other cars leads to inadequate energy absorption in the frontal structure and can result in very high passenger compartment

intrusion levels. This combined with variations in the frontal stiffness of cars and their passenger compartment strength results in them being incompatible with one another.

Although the issue of compatibility has been known since the 1960s, little systematic research has been performed until recently. The reason for this is that most research organisations consider an understanding and improvement of the performance of vehicles in frontal and side impact were required before addressing compatibility, as this offered the greatest and most immediate casualty benefits.

Vehicle incompatibility has often been identified in real-world accidents. It may result in unbalanced deformation between impacting cars or in poor management of energy absorption in both cars when they collide. One widely used example of incompatibility between cars is the case of a small passenger car impacting a heavy passenger car, where the small vehicle is excessively deformed with passenger compartment intrusion and the heavy vehicle has little passenger compartment damage. This generally accepted view that heavier vehicles have a much higher global stiffness than lighter vehicles and therefore could lead to incompatibility in car-to-car impacts has been found to be only one part of the crash configurations where incompatibility occurs.

In order to fully study compatibility, a project partially funded by the E.C. led the main part of the EEVC WG 15 activities from 1997 to 1999. The aims of this project were to identify how vehicle safety may be improved by developments to vehicle structures which are designed to interact better in an impact, and subsequently implement these changes in the vehicle fleet. This requires an understanding of the factors that influence compatibility and the development of new or modified test procedures to bring about greater compatibility. The project also aimed to identify the potential benefits that could be obtained from improved compatibility. One of the main concerns that was kept in mind during all activities was to propose an overall solution that could improve compatibility and therefore reduce overall traffic injuries resulting from car accidents without decreasing the self-protection of the involved cars.

This initial research has focused on the structural performance of the vehicles with the aim of providing a safe environment in which the restraint system of the occupant can operate. This approach is supported by the results from the recent EC funded accident analysis which showed that, e.g. for the UK, over 70% of the AIS 3+ injuries received by belted occupants were contact induced as opposed to restraint system induced. In Germany and Sweden similar distributions were found. Once the structure and the structural interaction between two cars provide a safe environment within which the restraint system can operate, the next step will be to control the cars' deceleration pulses in combination with more intelligent restraint systems. These should then provide the occupant with a more optimised ride down, for a variety of impact configurations and severities.

The approach taken for this project was to focus on car-to-car frontal impacts and car-to-car side impacts separately, in order to more clearly understand the controlling factors. This was different to the approach taken by NHTSA for the USA. Their approach was to construct a vehicle fleet model that would be used to assess a vehicle's compatibility. This work on building this vehicle fleet model continues. In addition, they have highlighted a particular problem concerning the mismatch of 'aggressive' sport utility vehicles (SUVs), light trucks and vans with cars in side impacts. This problem is being studied in North America but is currently less prevalent in Europe.

In this project, an attempt was made to achieve a better understanding of the compatibility problem. The goal is to reduce overall traffic injuries resulting from car accidents without decreasing the self-protection of the involved cars. From the start of the research work it was clear that not all compatibility questions could be answered in a short-term project.

WORKPLAN

Data from in-depth accident studies were used to identify the most important problems related to compatibility. These analyses were used to identify the most important circumstances when incompatible cars impact, and to show the main ways in which

their compatibility might be improved. The data was studied to indicate the extent to which improving compatibility might reduce the severity of the injuries sustained. Examples of cars exhibiting poor and less poor compatibility were identified to help in this analysis.

Typical accident configurations were replicated by carrying out experimental car-to-car impacts. These crash tests helped to identify the major problems occurring when two cars impact. Simpler impacts were also carried out, where the frontal characteristics of the vehicle could be understood more readily. As well as providing a better understanding of vehicle collision, such impact tests helped to explore the range of influence and potential gains that could result from improved compatibility.

Mathematical modelling was used to study the effects of changing the effective stiffness and mass of two impacting cars. This modelling could show the effects on vehicle deceleration and seat belt loading due to changes to the stiffness and relative mass of the impacting vehicles. The stiffness characteristics were varied to study their effects both before and after seat belt loading builds up on the occupant.

The results of the literature review conducted early in the project have been presented at the previous ESV-Conference [2]. To summarise, most previous studies concentrated on mass or mass ratio effects and extreme geometrical incompatibilities.

One other activity in the EEVC WG 15 activities was a structural survey of cars which was also been presented at the previous ESV-Conference [2]. The structural analysis method was adopted and refined by the US and Japan to classify their car fleets concerning geometrical incompatibilities of structures involved in car to car accidents.

At the beginning of the project, it was planned to make first attempts to assess potential benefits of compatible passenger cars and of a compatible car fleet in a sixth working package. It was found during the project that it was not reasonable to do this because vehicle incompatibilities (except mass) could not be clearly correlated to higher injury severities in real world accidents. Nevertheless some

assessments of potential benefits can be found in the final report.

RESULTS

Thanks to the E.C. contract and all the partners' contributions, the EEVC WG15 came to the following statements and conclusions about compatibility between cars. The presentation of these statements and conclusions has been split into several parts : overall results, what we do know, what we do not still know and what are the areas of common agreement with the other groups.

Overall Results

The case by case accident analyses, in combination with crash tests (car to car tests), gave the following results:

- the compartment intrusion is the main source of severe and fatal injuries in current car to car accidents
- many car to car accidents result in vehicle damage where the front end structures were not completely and ideally deformed (overall bending instead of buckling of the structure) and where at least one of the two passenger compartments was collapsed
- in accidents where the two impacting cars had a difference of mass, cases were identified where the driver of the lighter car was less injured than the one in the heavier opponent car
- overriding was frequently found in accidents and the result was that it generated an overcrush of the upper part of the overridden car compartment. This resulted in worse injury levels for the occupants of both vehicles than what would be expected from regulatory tests (ODB test)

There were many other illustrations of aggressivity or incompatibility between cars, in addition to the common example where a light/small car is overcrushed by a heavier/larger car. Moreover, if mass appears to be the main parameter linked to aggressivity of cars, it is because this is the easiest and universal parameter that is collected in all the accident databases. The current cars (recorded in the accident databases) usually have their mass linearly

linked to their stiffness. Therefore, the mass parameter can hide the influence of another physical parameter: the strength of the car front end (commonly called stiffness).

The ideal behaviour of the car front end (such as in a car to barrier test) is not met in car to car crashes. The actual crush behaviour of the car front end limits the energy dissipation within the car front structures and results in an overcrush of the car compartment in return.

What Do We Know

From these studies, it has been found that poor structural interaction occurs in current car to car accidents and results in compartment intrusion in one or both of the cars involved.

Moreover, even when front-end structures meet, they may not stay aligned during the crash and thus not deform as ideally as designed. This is strongly linked to overriding/underriding phenomena. Therefore, initial matching of the two cars structures is not sufficient. Their interaction during the crash also needs to be controlled.

These comments gave birth to the compatibility assessment: it is normal to find accidents where some structures of the car front end are not deformed properly resulting in poor energy absorption and passenger compartment intrusion. This means that the car structures have not worked as designed and that the potential energy dissipation through deformation in the car front end was not exploited. A compatible vehicle fleet will allow crash structures to perform as designed in a broader range of impact conditions and thus improve the safety performance of vehicles.

The bulkhead concept [3] is strongly linked to this statement. A maximum force level (the compatibility force) has to be defined for the front end of cars to force the two car front ends to be crushed before the collapse of the compartment. Criteria for occupant compartment performance to prevent intrusion will be linked to this compatibility force.

Another concept also linked to this compatibility assessment is that the energy absorption capacity of the car front end, as designed for self protection

requirements, is also required for car to car compatibility.

All of these ideas defined the first step that is required to improve compatibility. This first step being that improved structural interaction between colliding vehicles is a key pre-requisite to achieve good compatibility.

One idea to increase structural interaction was through improving the stiffness homogeneity of the front-end of the car, that is, a more uniform force distribution between the colliding vehicles.

The first research attempts to increase homogeneity have been made through drastic modifications of standard cars. It was found that this can lead to a dramatic change in the crash load-paths into the occupant compartment that resulted in undesirable intrusion in the car compartment.

From crash tests and simulation activities, it has been found that in order to assess homogeneity, a detailed knowledge of the force-time history is required. This is the reason why a high-resolution load cell wall was introduced and studied in the program.

In order to summarise the results we derived from our research activities, principles that can be used in developing more compatible vehicles are presented below.

Main Principles to Improve Compatibility in Frontal Impact:

Basic Principle: Improve compatibility without compromising self protection

- Good structural interaction;
- Predictable performance of car structures in crashes;
- Avoid passenger compartment collapse;
- Control the strength of the passenger compartment;
- Manage deceleration & time histories of both vehicles;
- Future capabilities of restraint technology;
- Respect the limitations of restraint system within the current fleet;

- Staged approach addressing one of the above items at a time.

Main Principles to Improve Compatibility in

Lateral Impact:

Basic Principle: consider self protection and current bullet car fleet

- Geometry has the greatest effect;
- Mass and stiffness have smaller effects;
- Vertical intrusion profile;
- Stiffness distribution of bullet vehicle;
- Promote sill engagement;
- Front structure of bullet vehicle must not produce thoracic lead;
- Distribute loading to the occupant;
- Frontal stiffness distribution of the bullet vehicle may be only relevant about the first 100 mm.

It was determined that, for car to car frontal impacts, the structural interaction between the two cars, the strength of the car front end and the strength of the passenger compartment are the first criteria that should be studied to help in the assessment of compatibility.

In order to do so, some potential test candidates have been proposed and studied for assessing frontal compatibility. These are:

- Full width frontal impact on a load sensing wall (with or without honeycomb), to assess the homogeneity of the force distribution of the car front end and so assess its structural interaction capability;
- EEVC or EuroNCAP Offset Deformable Barrier test with force sensing wall, to measure frontal stiffness;
- Overload test to measure passenger compartment strength before collapse (if this level has not been reached in EuroNCAP ODB test);
- Progressive Deformable Barrier test (PDB) with partial overlap to generate vertical and lateral shear forces within the front end of the vehicle. The shear is generated thanks to the design of the barrier since it is made of progressive honeycombs designed to have the

global behaviour of a car with its non-uniform stiffness distribution). This is made to assess the structural interaction capability and the frontal stiffness.

These candidate tests are still under definition and discussion. The discussions are strongly linked to the following section that deals with the limits of our current knowledge.

What We Still Do Not Know

Structural interaction was agreed to be a pre-requisite to achieve good compatibility between cars.

A hypothesis to reach this goal is to assess the level of homogeneity of the car front end. In order to do so, two potential candidates have been proposed (as already described above).

In the Full Width Barrier test with a high-resolution load cell wall the car front end stiffness distribution will be studied to identify localised stiffness areas. What criteria to assess the results of this test procedure are still not known and, moreover, we do not know if homogeneity (as tested in the full width test configuration) is an adequate indicator of structural interaction capability.

The Progressive Deformable Barrier (PDB) test with partial overlap is intended to assess the stiffness level and its distribution of the car front end, when impacting an obstacle which deforms like another car.

However, we still do not know if the energy absorption capacity of the barrier could be counter productive. For example, it is feared that the car manufacturers may use the high absorption level capacity of the barrier to reduce the energy to be absorbed by the car.

Moreover, we do not know which criteria to use with the test. The criteria need to be objective and none have yet been proposed for the PDB test.

For both tests, substantial information will be available (e.g. 128 channels of the force-time evolution, digitalized barrier deformation). It is necessary to define criteria to analyse these signals in an efficient way.

One proposal that is promising is to use an average height of force criteria associated to a foot print parameter that could assess the contact surface between the two cars front end. This procedure has shown promising in a US study [4].

Finally, the limit value for the compatibility force (i.e. the maximum level of force of the car front end and the minimum force level for the passenger compartment) yet to be defined will be linked to the type of configuration chosen. Indeed, it is known that the force level of the car front end in crash against a full width wall differs from the one in a crash with partial overlap.

What Are the Areas of Common Agreement with the Other Groups (within EEVC WG15 and with EUCAR and IHRA compatibility groups)

EEVC WG 15 is not the only co-ordinated group working on compatibility. Its research activities were partially funded by the E.C. and fed by members' national contributions, but it also shares experience and results with the EUCAR Compatibility group and the IHRA Compatibility group.

Thanks to fruitful exchanges and discussions within formal meetings and within workshops, some key points have been identified as common agreement within all the groups.

First of all, the basic principle is universally agreed: there is a need to improve compatibility but this must be achieved without compromising self-protection.

Moreover, the assessment that structural interaction is a key pre-requisite to achieve good compatibility between cars has been quickly incorporated into all the discussions on compatibility world-wide.

The bulkhead concept, i.e. the need to prevent or minimise compartment intrusion as long as there is some energy dissipation capacity in the cars front-end, is also commonly agreed.

Some differences in research priorities are still present between the different groups. They are often linked to local fleet distribution and crash configuration. For instance NHTSA wants to deal with compatibility between passenger cars and LTVs, therefore it has a concern with respect to the

mass issue. Moreover, it is also concerned with angled impacts and this results in a crash configuration where a Mobile Deformable Barrier is the best suitable test tool.

CONCLUSION

Compatibility issues have been identified in case by case accident analyses and by crash tests.

The common image that had been widely used to illustrate compatibility i.e. the case of a small passenger car impacting a heavy passenger car, resulting in severe injury risks only to the occupants of the small vehicle (because of excessive intrusion of the passenger compartment), is just only one part of the problem. The contrary can occur, as well as the case of a car to car impact with two identical cars where these two cars can experience different deformation behaviour. These differences can be attributed to poor structural interaction resulting in phenomena such as overriding. Therefore compatibility appeared to reflect a wider range of problems than was initially thought.

It has also been found that there is a possibility for more compatible cars. It has been agreed world-wide that structural interaction is a pre-requisite to achieve good compatibility. The bulkhead concept and the compatibility force level have also been derived from the research activities. This first step has given birth to some potential test candidates: a full-width deformable barrier test, a EuroNCAP type Offset Deformable Barrier test, an Offset Deformable Barrier Overload test and Progressive Deformable Barrier test. Further research into these potential test candidates is required to ensure that they achieve the required effect and to develop assessment criteria.

This work is anticipated in future research activities. Within EEVC WG15, co-ordinated activities are already planned to be funded by a grant from DGTREN for the year 2001 as well as a 5th Framework Program project beginning in 2002. Moreover, national compatibility projects for EEVC members are still going on in several countries and the collaboration with European industry is always strongly encouraged. This co-ordinated research will lead to the proposal of a suitable test candidate to

assess vehicle compatibility and thereby improve the protection of car occupants.

ACKNOWLEDGEMENTS

The authors would like to thank the EEVC Steering Committee and the E.C. that as funded the group. They would like to thank EUCAR group and the IHRA Compatibility group for their fruitful discussions and co-operation for all the technical aspects related to compatibility.

They would also like to thank all the participants of the EEVC WG15 from 1998 to 2001:

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